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Sleep Self-Efficacy, Loneliness, and Physical Activity: Assessing the Pathways between Sleep Quality and Mental Health using Structural Equation Modeling

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

by

Amber Fox
Bachelor of Science, University of Maryland, College Park, 2016

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Virginia Commonwealth University
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Abstract

SLEEP SELF-EFFICACY, LONELINESS, AND PHYSICAL ACTIVITY: ASSESSING THE PATHWAYS BETWEEN SLEEP QUALITY AND MENTAL HEALTH USING STRUCTURAL EQUATION MODELING

By Amber M. Fox, B.S.

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Virginia Commonwealth University, 2022

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Although there is robust empirical support that poor sleep contributes to declines in mental health, explanations of this relationship remain unclear. The purpose of the present study was to examine the pattern of associations between sleep quality, sleep self-efficacy, loneliness, physical activity, and mental health among U.S. adults across the lifespan, and whether they differed by gender or age group. A structural equation model with invariance analysis was developed and examined data from 2,300 adults (M_{age} = 44.1, *SD* = 16.78) participating in the online study Investigating Sleep Longitudinally Across Normal Development (ISLAND). Sleep quality was measured by the RU-SATED and Insomnia Severity Index. Mental health was measured by the GAD-2, PHQ-2, and PANAS. Sleep self-efficacy was measured by the sleep self-efficacy scale. Loneliness was measured by the de Jong-Gierveld Loneliness Scale. Physical activity was measured by a calculation of average amount of moderate to strenuous exercise per week and average proportion of sedentary time. Results revealed a significant direct effect of sleep quality on mental health and indirect effect of sleep quality on mental health via loneliness.

Indirect effects of sleep quality on mental health via sleep self-efficacy and physical activity were not significant. Overall, the model was invariant across gender and across age groups, except the direct effect of loneliness on mental health was stronger among young adults relative to older adults. Findings suggest that poor sleep quality was associated with greater loneliness and, in turn, associated with greater severity of mental health symptoms. Further research is needed to delineate directionality and causality among sleep quality, loneliness, and mental health.

Keywords: insomnia, sleep health, self-efficacy, loneliness, physical activity, mental health

Sleep Self-Efficacy, Loneliness, and Physical Activity: Assessing the Pathways between Sleep Quality and Mental Health using Structural Equation Modeling

Mental health concerns in the United States (U.S.) are rising, increasing the need for accurate prevention and intervention strategies. The number of adults seeking help for and diagnosed with anxiety and depression are increasing at alarming rates (Mental Health America, 2021). Given that depression (8.4%) and anxiety disorders (19.1%) have the highest annual prevalence rates of mental disorders, among U.S. adults (National Alliance on Mental Illness, 2021), the present study primarily focused on these mental health symptoms. Developing more efficacious and effective treatments for mental health requires that research investigate the etiology underlying mental health disorders.

Similarly, sleep problems in the U.S. are of growing concern and have complex ties to mental health. Sleep is a concern for approximately half of Americans, who report feeling sleepy during the day for at least half the week (National Sleep Foundation, 2020). Mixed findings have identified correlations between sleep problems and mental health (Bouwmans et al., 2017; Hertenstein et al., 2019; Khurshid, 2018; Taylor et al., 2005) and have also supported a potential bidirectional relationship between the sleep problems and mental health (Alvaro et al., 2013; Difrancesco et al., 2021; Jansson-Fröjmark & Lindblom, 2008; Konjarski et al., 2018). Sleep problems and mental health concerns are each associated with a wide array of negative health outcomes and associated costs (Hafner et al., 2017; Hillman et al., 2018). Despite the substantial research supporting the link between sleep and mental health and their robust impact on health and wellbeing, there is limited research examining explanatory pathways for how sleep and mental health are related. To improve the current understanding of the connection between sleep and mental health, the present study explored three potential mediators, supported by theoretical and empirical research.

Literature Review

Sleep Quality

Widespread poor sleep across the U.S. negatively impacts physical and mental health outcomes and is associated with significant socioeconomic cost. As a result, the U.S. has declared sleep deprivation a national public health crisis. Over one-third of U.S. adults experience short sleep duration, defined as insufficient sleep duration of less than seven hours of sleep per night (Consensus Conference Panel [CCP] et al., 2015; National Center for Chronic Disease Prevention and Health Promotion [NCCDPHP], 2017). Short sleep duration is associated with health risk factors (e.g., obesity, smoking), chronic physical and mental health conditions (e.g., cardiovascular disease, cancer, depression), and increased risk for all-cause mortality, regardless of age and socioeconomic status (Cappuccio et al., 2010; Gallicchio & Kalesan, 2009; NCCDPHP, 2017). Further, prior studies estimate that the annual economic cost associated with inadequate sleep in the U.S. (e.g., cost of treatment for sleep disorders and associated health conditions, productivity loss due to reduced employment, premature death, absenteeism, nonmedical accidents, etc.) ranges from $280-$585 billion annually, and is compounding over time (Hafner et al., 2017; Hillman et al., 2018). Due to common under-diagnosis of sleep disorders (Huyett et al., 2020; Ram et al., 2010), these projected economic costs are likely underestimates. Given the detrimental effects of insufficient sleep on health and well-being as well as its negative societal and economic impact, it is critical that research characterize and examine the etiology and consequences of both disordered and healthy sleep to develop effective prevention strategies and clinical interventions.

Insomnia

Throughout history, the field of sleep medicine focused on the evaluation, assessment, and treatment of sleep disorders, notably insomnia (Kirsch, 2011). Although many empirical

studies examined the epidemiology of insomnia and evaluated the efficacy of insomnia interventions, research still lacks consensus on the definition of and protocol for assessing insomnia (Morin & Jarrin, 2013; Ohayon, 2011). However, insomnia is commonly characterized by dissatisfaction with quality, quantity, and continuity of sleep, as well as dysfunction due to these sleep problems (Morin & Jarrin, 2013; Ohayon, 2011). According to a recent study, in a given year, approximately 27% of adults are diagnosed with acute insomnia and 2% with chronic insomnia (Perlis et al., 2020). Yet, these rates are likely an underestimate due to regular underdiagnosis of sleep disorders (Ram et al., 2010). Subjective (e.g., self-report) and objective (e.g., actigraphy, polysomnography) measures of sleep are supported as valid and reliable methods of assessing insomnia symptoms, complementary to one another (Buysse et al., 2006; Morin et al., 2011a). Although insomnia has been a prominent focal point of sleep medicine research, additional research is needed to improve the treatment of insomnia and the understanding of its link to negative health outcomes.

Sleep Health

In recent years, the understanding that health and well-being are greater than simply the absence of disease and disorder has expanded across health fields, including sleep medicine and mental health. Although good sleep is vital to cultivating health and well-being, sleep health is rarely defined or assessed in research. Thus far, a universal definition of sleep health does not exist; however, Buysse (2014) defines sleep health as "a multidimensional pattern of sleep-wakefulness, adapted to individual, social, and environmental demands, that promotes physical and mental well-being," and describes that, "good sleep health is characterized by subjective satisfaction, appropriate timing, adequate duration, high efficiency, and sustained alertness during waking hours" (p. 12). Sleep health may further be conceptualized across six dimensions

including sleep regularity, satisfaction with sleep, alertness during waking hours, timing of sleep, sleep efficiency, and sleep duration (Buysse, 2014). Moving beyond sleep medicine's historical focus on sleep disorders toward integrating the examination and evaluation of sleep health may broaden the utility of sleep research. Holistically viewing sleep health as a continuum allows for the inclusion of individuals who may not meet the threshold for sleep disorders in a traditional categorical view of sleep, therefore expanding the reach of potential educational and health promotion initiatives and subsequent intervention efforts (Buysse, 2014). Advancing our understanding of sleep requires that sleep research expand to also include the evaluation and examination of sleep health.

Sleep and Mental Health

Sleep disturbance (e.g., insomnia) is associated with negative mental health symptoms, including depression and anxiety symptoms, as well as negative affect. Relative to those without insomnia, individuals with insomnia are estimated to be nearly 10 times more likely to have clinically significant depression and over 17 times more likely to have clinically significant anxiety, even after controlling for a variety confounding variables (e.g., body mass index, neurological problems, diabetes, cigarette smoking) (Taylor et al., 2005). Indeed, insomnia, depression, and anxiety symptoms are frequently comorbid, with the presence of insomnia symptoms among 90% of cases of clinical depression and 33% of those with insomnia also having an anxiety disorder diagnosis (Khurshid, 2018). Beyond being a symptom of depression and anxiety or a common comorbid condition, insomnia may increase individual risk for psychopathology. Specifically, recent meta-analytic data supported insomnia as a significant predictor for 2.8x and 3.2x greater risk of onset of depression and anxiety, respectively (Hertenstein et al., 2019). Additionally, changes in sleep quality predict corresponding changes

in negative affect. Worse sleep quality predicts increased next day negative affect and increased negative affect in a given day predicts further increases in negative affect the following day (Bouwmans et al., 2017). The substantial evidence supporting the significant association of insomnia symptoms with symptoms of depression, anxiety, and negative affect underscores the importance of examining the nature of these relationships.

Although sleep disturbances have often been addressed as resulting from mental health disorders, sleep disturbances may serve as an independent predictor of mental health. Over time, research has supported a bidirectional relationship between sleep disturbances and mental health (e.g., depression, anxiety, and negative affect). Longitudinal research supports that sleep disturbances (e.g., insomnia) predict future depression and anxiety; and, anxiety and depression predict future insomnia and associated symptoms, such as excessive daytime sleepiness (Alvaro et al., 2013; Jansson-Fröjmark & Lindblom, 2008). A systematic review of 29 naturalistic prospective studies concluded that, across the lifespan and among healthy as well as clinical samples, sleep quality and duration are each associated with changes in positive and negative affect the next day, such that poor sleep quality and shorter sleep duration are associated with reduced positive affect and increased negative affect (Konjarski et al., 2018). Conversely, daytime positive affect is associated with improved subjective sleep quality the next day and negative affect is found to have low day-to-day impact on sleep, but is supported to have a cumulative effect that may be detected when assessing sleep for at least two weeks (Konjarski et al., 2018). In particular, the bidirectional relationship between sleep and affect is identified when sleep is assessed subjectively rather than objectively (Difrancesco et al., 2021; Konjarski et al., 2018). While the relationship between sleep and mental health is complex, there is significant research that supports sleep as a predictor of mental health symptoms. A recent meta-analysis of

longitudinal studies found sleep disorders to be a significant longitudinal risk factor for the development of depression (M.-M. Zhang et al., 2022). Thus, the support for sleep disturbances as a predictor of mental health in the literature, as well as how sleep may predict mental health, warrants further investigation.

Despite the established relationship between sleep disturbances and mental health, few studies have investigated possible explanations of this relationship. A recent review proposed a complex biopsychosocial model and associated mechanism (e.g., mesolimbic dysregulation of positive and negative affect, negative emotionality including low self-worth and sadness, impaired social interactions) that may explain the association between insomnia, anxiety, and depression among adolescents (Blake et al., 2018). Another study found evidence supporting that rumination and anxiety mediate the association of loneliness with depressive symptoms and poor sleep quality among a sample of college students (Zawadzki et al., 2013). Broadly, it has been proposed that inadequate sleep may impair emotional information processing, reactivity, and control, leading to negative affect (Kahn et al., 2013; Konjarski et al., 2018). Of the few studies that have attempted to explain the relationship between sleep and mental health, the proposed models are disparate and the findings remain inconsistent. Therefore, further research investigating potential pathways between sleep and mental health is warranted.

Finally, sleep and mental health each vary based on age and gender. The recommended amount of sleep reduces as age increases (Hirshkowitz et al., 2015; Panel et al., 2015). In line with these recommendations, various aspects of sleep change across the lifespan. Sleep duration and sleep timing drastically shift throughout adolescence and early adulthood (Kuula et al., 2019). Sleep characteristics also appear differently based on gender. From adolescence to early adulthood, females tend to sleep more and sleep earlier than males (Kuula et al., 2019). Across

the lifespan, women are at greater risk for sleep disturbances at periods of hormonal shifts, and men tend to sleep less (Jonasdottir et al., 2021; Pengo et al., 2018). Mental health (e.g., depression, anxiety) also varies by age and gender, such that prevalence of affective disorders is higher among females than males and that the degree of gender difference in prevalence changes as a function of age (Faravelli et al., 2013). When examining associations between sleep and mental health, it is important to consider potential variations based on age and gender.

Potential Pathways between Sleep and Mental Health

Given the current gaps in the literature, the present study seeks to examine the potential pathways linking the continuum of sleep quality (e.g., insomnia and sleep health) and highly prevalent mental health symptoms (e.g., depression, anxiety, and negative affect). The cognitive behavioral model of mental health describes that maladaptive thoughts, feelings, and behaviors are interrelated and contribute to negative mental health outcomes. The present study will use the cognitive behavioral model of mental health as the guiding framework to assess whether thoughts (e.g., sleep self-efficacy), feelings (e.g., loneliness), and behaviors (e.g., physical activity) explain the association between sleep quality and mental health (see Figure 1).

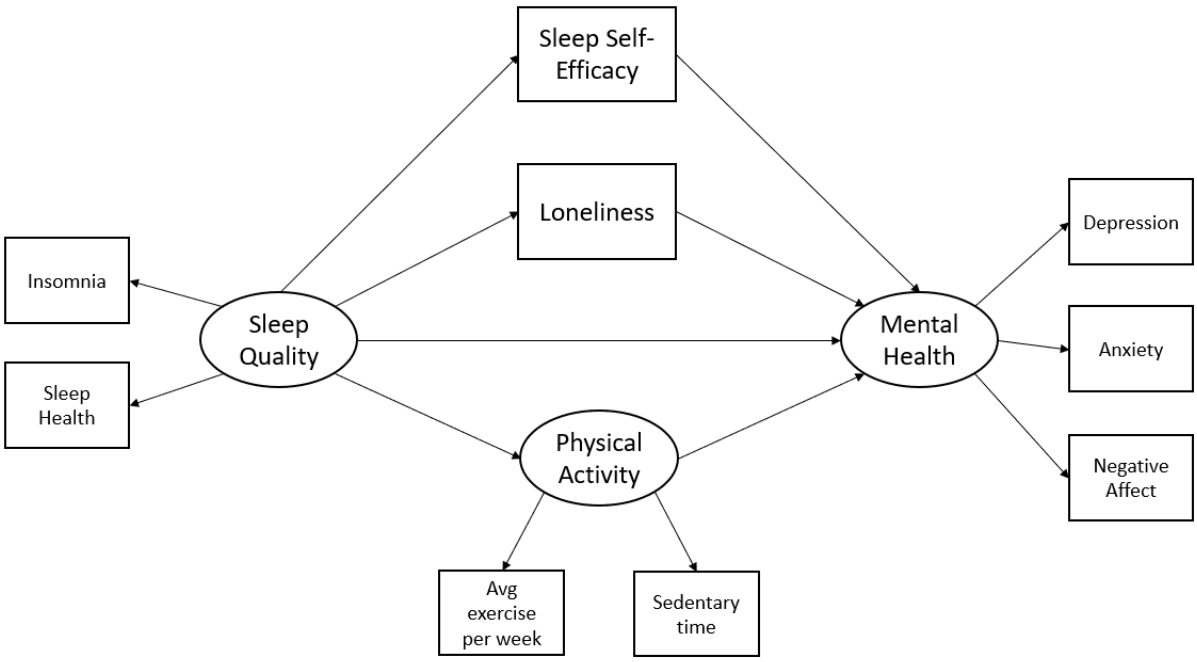

Figure 1. Proposed model of the present study.

Sleep Self-Efficacy

Sleep self-efficacy may serve as a cognitive link between poor sleep quality and negative mental health symptoms. Self-efficacy is a mechanism of human agency, representing one's core belief in their capacity to execute behaviors to intentionally influence events and produce desired effects (Bandura, 1977, 1982). Particularly in the face of challenges and obstacles, self-efficacy influences one's motivation, choices, performance, and well-being (Bandura, 1977). In the context of mental health, self-efficacy influences the initiation of, effort expended for, and persistence of coping behaviors in stressful circumstances (Bandura, 1977, 1989). Experimental research also supports that self-efficacy has a causal effect on intention and behavior that impacts health behaviors (Sheeran et al., 2016). In the context of sleep, self-efficacy related to sleep comprises one's belief in their capacity to engage in or to alter their sleep-related behaviors (i.e., sleep self-efficacy) (Lacks, 1987). Increased sleep disturbances may contribute to reduced sleep self-efficacy, which influences coping and other health behaviors.

Sleep Self-Efficacy and Sleep. Experiencing sleep disturbances (e.g., insomnia) is associated with harmful beliefs about sleep. The cognitive model of insomnia describes how sleep disturbances lead to a cycle of negative cognitive processes that maintain and exacerbate sleep problems. Specifically, maladaptive sleep-related cognitions (e.g., excessive worry about sleep and the associated daytime consequences) increase arousal and emotional distress, leading to distorted attention, perception, behaviors, and beliefs related to sleep which, in turn, negatively impact sleep and daytime functioning (Harvey, 2002). The cognitive model of insomnia suggests that insomnia treatment should target the negative cognitive processes associated with sleep problems, rather than total sleep time or the time it takes to fall asleep (Harvey, 2002). The cognitive model of insomnia has been supported by research identifying that individuals with poor sleep experience greater sleep-related rumination than individuals with good sleep, and insomnia-specific rumination is associated with insomnia severity (Carney et al., 2013). Sleep disturbances precede negative cognitive processes related to sleep that perpetuate sleep problems. One form of harmful beliefs about sleep that result from sleep disturbances include negative beliefs about one's capacity to change their sleep quality (i.e., sleep self-efficacy).

Sleep Self-Efficacy and Mental Health. Sleep self-efficacy is associated with mental health symptoms. In earlier cross-sectional research including sleep self-efficacy, elevated insomnia severity was found to be significantly associated with reduced health status and sleep self-efficacy, as well as increased dysfunctional beliefs and depression, suggesting that interventions for insomnia and comorbid depression should target sleep self-efficacy to improve insomnia severity as well as mood and well-being (Bluestein et al., 2010). These findings were expanded upon by examining correlates of sleep self-efficacy. Examined among 236 primary

care patients with insomnia, sleep self-efficacy is negatively associated with health status, insomnia severity, depressive symptoms, dysfunctional beliefs about sleep, and treatment acceptability of behavioral interventions for insomnia (Rutledge et al., 2013). In substance use research, sleep-self efficacy is significantly positively associated with sleep quality and negatively associated with relapse among individuals with alcohol use disorder both at baseline and at four weeks follow-up (Brooks et al., 2021). Although actigraphy recorded sleep variables were not significantly different between individuals who did and did not relapse, cognitive variables (e.g., sleep self-efficacy) did significantly differ between groups (Brooks et al., 2021). Among the few studies that have investigated associations between sleep disturbances, sleep self-efficacy, and mental health symptoms, the specific interactions among these variables within the sleep-mental health relationship has yet to be studied.

Loneliness

Loneliness may serve as an affective link between sleep quality and mental health symptoms. According to a 2019 survey of 10,000 U.S. adults, approximately 61% of U.S. adults report feeling lonely, up from 54% the year prior (Cigna, 2020). Loneliness has been defined as negative feelings associated with a perceived discrepancy between one's actual and desired levels of social relationship (Peplau & Perlman, 1982). Although highly prevalent, loneliness fluctuates across the lifespan. Loneliness has a nonlinear relation to age, such that loneliness is elevated among young adults (<30 year), middle-aged adults (50-60 years), and very old age (>80 years) (Hawkley et al., 2020). Despite changes in loneliness associated with age, the experience of loneliness across the lifespan is supported to be similar among males and females (Maes et al., 2019). Given the rising prevalence of loneliness within the U.S., the consequences of loneliness are of increasing concern. Ample research examining loneliness has identified its

detrimental effects on health and well-being, associated with a vast increased risk for physical health, mental health, and cognitive health concerns, as well as mortality (Holt-Lunstad et al., 2015; Lim et al., 2020; Rico-Uribe et al., 2018). Often studied as a consequence of other health concerns, loneliness also serves as a predictor of health concerns (Lim et al., 2020). Given the considerable consequences associated with loneliness and its association with negative mental health outcomes, loneliness is a prominent variable to examine in the context of mental health.

Loneliness and Sleep. Recent research has established an association between sleep quality and loneliness. A meta-analysis examining 27 articles on sleep and loneliness supported that loneliness is correlated with self-reported sleep disturbance (i.e., poor sleep quality, insomnia) as well as sleep inadequacy and dissatisfaction (Griffin, Williams, Ravyts, et al., 2020). There have been mixed results regarding whether changes in sleep or sleep quality longitudinally predict loneliness and, still, the role of mental health symptoms, such as depression, in this relationship is unknown (Griffin, Williams, Ravyts, et al., 2020). Findings of this meta-analysis led to the recommendation that future research examine the nature of the relationships among sleep disturbance, loneliness, and depression (Griffin, Williams, Ravyts, et al., 2020). Another study which reviewed six articles and conducted a meta-analysis among these studies also supported the significant association between insomnia severity and greater loneliness, even when controlling for confounding variables such as nightmares, anxiety symptoms, and perceived burdensomeness (Hom et al., 2017). However, the association between insomnia and loneliness was attenuated in some of the studies, after controlling for depression (Hom et al., 2017). Additionally, longitudinal analysis corroborated the association between sleep and loneliness, and this association remained even after controlling for depression (Griffin,

Williams, Mladen, et al., 2020). Although there is a well-supported relationship between sleep and loneliness, the role of mental health symptoms within this relationship remains uncertain.

Loneliness and Mental Health. Loneliness is associated with negative mental health symptoms, cross-sectionally and longitudinally. First, in a sample of 318 U.S. college students examining the interaction of hope and loneliness, loneliness significantly predicted anxiety and depressive symptoms (Muyan et al., 2016). Second, a latent class analysis examining subtypes of loneliness among 1,839 U.S. adults found that regardless of loneliness class (e.g., social loneliness, emotional loneliness, social and emotional loneliness), individuals with any type of loneliness reported worse psychological well-being and greater depressive and anxiety symptoms, relative to those with lower loneliness (Hyland et al., 2019). A meta-analysis examining the effects of loneliness on depression across 88 studies also supported the positive relationship between loneliness and depression, with loneliness as a significant predictor of depression (Erzen & Çikrikci, 2018). Further, longitudinal research has identified loneliness as a predictor of future mental health outcomes. One study examining loneliness and mental health across four time points over a year, among 454 British undergraduate students, supported loneliness as a predictor of increased stress, eating disorder symptoms, anxiety, depression, and general mental health concerns cross-sectionally as well as longitudinally (Richardson et al., 2017). Interestingly, mental health was not supported as a predictor of loneliness (Richardson et al., 2017). With loneliness as a well-supported predictor of mental health, examining loneliness as a mediator between sleep quality and mental health may expand the current understanding of the interaction between these three variables. s

Physical Activity

Physical activity may serve as a behavioral link between sleep quality and mental health symptoms. In the present study, degree of physical activity is defined by average daily and weekly moderate to strenuous exercise and proportion of sedentary time (i.e., time spent sitting while awake) per day. Physical activity is associated with a variety of positive physical (e.g., reduced risk of diabetes-related health complication, cardiovascular disease, cancer incidence and mortality) and mental (e.g., reduced depression and anxiety, increased health-related quality of life) health outcomes (Penedo & Dahn, 2005). Conversely, sedentary time is associated with reduced physical (e.g., obesity in childhood and adolescence, cardiovascular disease, mortality) and mental (e.g., psychological distress, mental disorders) health outcomes (Hamer et al., 2014; Thorp et al., 2011). Physical activity has strong ties to both physical and mental health. Accordingly, physical activity may represent a health behavior through which sleep quality and mental health are related.

Physical Activity and Sleep. Poor sleep leads to reductions in physical activity. With insomnia and sleep disturbances being characterized by daytime sleepiness and dysfunction, it is plausible that individuals with lower quality sleep are less likely to readily engage in physical activity and are likely to spend more time sedentary during their waking hours. This pattern of behavior has been identified in a study of 48 young adults at risk for diabetes type-2, where those with short sleep duration also reported spending less time engaged in physical activity and more time sedentary, relative to those with longer sleep duration (Booth et al., 2012). When examining potential bidirectional associations between sleep quality and physical activity among older adults, sleep quality is identified as an important predictor of future physical activity, but physical activity is not predictive of sleep. Specifically, a longitudinal analysis examining sleep quality and physical activity over a two-year period among 426 older adults (e.g., 61+ years),

supported sleep quality as a predictor of future physical activity, over and above the effects of prior physical activity; and, physical activity did not predict future sleep quality (Holfeld & Ruthig, 2014). These effects remained even after controlling for age, gender, perceived stress, functional ability, and chronic health conditions (Holfeld & Ruthig, 2014). The findings that sleep quality predicts future physical activity were also supported in a study assessing sleep and physical activity across sixteen weeks among a group of women with insomnia (Baron et al., 2013). In this study, sleep quality predicted next day exercise, but exercise did not predict sleep quality the next night (Baron et al., 2013). Further, this association was magnified among participants with short sleep duration (Baron et al., 2013). Additionally, the relationship between sleep and physical activity may vary by age. In a nationally representative sample of U.S. adults, participants who reported more frequent daytime sleepiness engaged in less physical activity for young and older adults, but not middle-aged adults (McClain et al., 2014). However, sedentary time was not associated with sleep duration (McClain et al., 2014). Sedentary time is recognized as a health risk factor, independent of exercise, and is associated with increased insomnia and sleep disturbance (Yang et al., 2017). Overall, consequences of poor sleep quality may lead to reduced engagement in physical activity and a greater proportion of sedentary time.

Physical Activity and Mental Health. Physical activity is a frequently targeted point of intervention for mental health treatment due to its pronounced influence on mental health. An examination of the association between physical activity and mental disorders among a nationally representative sample of U.S. adults between 15-54 years, identified that regular physical activity was associated with reduced prevalence of current depressive and anxiety disorders, that remained even after controlling for sociodemographic characteristics, physical disorders, and comorbid mental disorders (Goodwin, 2003). Further, longitudinal research

supports the association between physical activity and mental health. In a 10-year cohort study of 424 adults with depression, after controlling for age, medical problems, and negative life events in the last three months, physical activity was associated with lower concurrent depression, but not subsequent depression, and served as a buffer for the effects of medical conditions and negative life effects on depression (Harris et al., 2006). Although physical activity declines with age, physical activity is still negatively associated with depression in middle through older adulthood, such that increased intensity, duration, and type of physical activity (e.g., recreation-related relative to work-related) predicts reduced depression (Mumba et al., 2021). Such extensive research examining physical activity and mental health has been conducted that a meta-meta-analysis analyzed the findings of 8 high quality meta-analytic outcomes of randomized trials that investigated the effects of physical activity on depression or anxiety in non-clinical populations and concluded that physical activity reduced depression with a medium effect and anxiety with a small effect(Rebar et al., 2015). In response to the body of research supporting physical activity as a predictor of mental health, many interventions have been developed for the treatment of mental health that target increasing physical activity (Conn, 2010a, 2010b). Despite the vast evidence supporting the associations between physical activity, sleep, and mental health, few studies have examined the interaction between these variables. However, a recent study examining the relationships among sleep quality, mental health, physical activity and diet among a sample of Chinese older adults provided support for physical activity as a partial mediator between sleep quality and mental health (Zhao et al., 2021). Reduced physical activity may not only predict mental health outcomes but may also serve as an explanatory factor for the relationship between sleep and mental health.

The Present Study

Purpose

The present study sought to investigate potential mediators through which sleep quality and mental health symptoms are related. Although the association between sleep quality and mental health symptoms are well established, the nature of this relationship remains poorly understood. In the present study, sleep quality was defined by both disordered and healthy sleep (i.e., insomnia, sleep health) and mental health is defined by mental health symptoms commonly associated with sleep problems (i.e., depressive symptoms, anxiety symptoms, negative affect). Using a cognitive behavioral framework of mental health, the present study evaluated how sleep is associated with mental health through thoughts, feelings, and behaviors. To represent each of the components of the cognitive behavioral triad, sleep self-efficacy, loneliness, and physical activity were examined as potential mediators through which sleep quality and mental health symptoms are related. Sleep quality is supported to be associated with each sleep self-efficacy, loneliness, and physical activity, and each of these variables are associated with mental health symptoms. Further, because several of the variables of interest vary with gender (e.g., sleep quality, mental health symptoms) and age (e.g., sleep quality, mental health symptoms, loneliness), the present study examined how the associations within this mediation model change as a function of gender and age.

Aims and Hypotheses

Aim 1

To examine the pattern of associations that connect the continuum of sleep quality (represented by insomnia and sleep health) and mental health symptoms (represented by depression, anxiety, and negative affect), through thoughts, feelings, and behaviors (respectively, sleep self-efficacy, loneliness, and physical activity).

Hypothesis 1a. Sleep quality will be directly associated with mental health symptom severity.

Hypothesis 1b. Sleep self-efficacy will mediate the association between sleep quality and mental health symptoms severity, such that there will be an indirect effect of sleep quality on mental health symptom severity through sleep-self efficacy.

Hypothesis 1c. Loneliness will mediate the association between sleep quality and mental health symptoms severity, such that there will be an indirect effect of sleep quality on mental health symptom severity through loneliness.

Hypothesis 1d. Physical activity will mediate the association between sleep quality and mental health symptoms severity, such that there will be an indirect effect of sleep quality on mental health symptom severity through physical activity.

Aim 2

To determine whether the patterns of association between sleep quality, mental health symptom severity, sleep self-efficacy, loneliness, and physical activity differ based on confounding demographic variables (e.g., gender, age).

Hypothesis 2a. The patterns of associations between sleep quality, mental health symptom severity, sleep self-efficacy, loneliness, and physical activity will differ between participants who identify as female versus male.

Hypothesis 2b. The patterns of associations between sleep quality, mental health symptom severity, sleep self-efficacy, loneliness, and physical activity will differ between participants based on age group (young adults: 18-34, middle-aged adults: 35-54, and older adults: 55+ years).

Method

Participants

The present study utilized a subset of data collected as a part of wave 1 of a larger, Institutional Review Board-approved (Virginia Commonwealth University IRB#: HM20008543) online study Investigating Sleep Longitudinally Across Normal Development (ISLAND) funded by the National Institute on Aging (K23AG049955, PI: Dzierzewski). Wave 1 data were collected between February-July of 2018. Inclusion criteria required that participants reside within the U.S. and be at least 18 years of age. Additionally, inclusion and exclusion criteria were integrated to facilitate age and gender variability within the sample, accounting for attrition across this longitudinal study.

The sample size for the present study was refined based on data validity checks and measure completion. First, attention and accuracy safeguards were integrated into the survey battery to reduce potential threats to data validity. Specifically, the attention check required participants to provide a specific item response and the accuracy check compared two items related to the participant's age to assess response consistency. The accuracy check items were placed at the beginning and end of the survey to support their validity. Only participants who passed both validity checks were included in the proposed analyses. Second, the de Jong-Gierveld Loneliness Scale was added to the survey battery one week following the survey's initial publishing. Thus, participants who did not complete the loneliness measure were removed from the statistical analyses. The survey was constructed such that participants were required to respond to every item, thus there was no missing data.

For wave 1 of data collection for the ISLAND study, there were initially 4,678 total survey responses. Accordingly, to refine the sample, participants were removed sequentially as follows: failed age validity check (n = 902, 19.3%), failed attention validity check (n = 209, 4.5%), missing loneliness measure responses (n = 987, 21.1%), duplicate survey responses (n =

280, 6.0%). Data from the remaining 2,300 participants (49.2%) were included in data analyses for the present study.

Procedure

Data were collected via Amazon's Mechanical Turk (MTurk), a crowdsourcing online platform where individuals may complete a variety of virtual tasks for compensation. Individuals self-selected and provided informed consent to participate in the ISLAND study. Participation required access to this online platform via computer, tablet, or phone to complete a series of behavioral and psychological self-report measures via Qualtrics, with a duration of approximately 20-25 minutes. For their participation, participants were compensated $0.50 USD. Compensation has not been supported to affect the quality of data collected via MTurk (Buhrmester et al., 2016). Data collected via MTurk has continued to increase in recent years, and has been supported as a reliable method of data collection (Mortensen & Hughes, 2018; Necka et al., 2016; Rouse, 2015).

Measures

Demographic Characteristics

Participants were asked to provide demographic information including age, gender (i.e., male, female, other), highest level of completed education, race/ethnicity, marital status, employment status, residential time zone, and medical and mental health history.

Sleep Quality

Sleep Health. The RU-SATED (Buysse, 2014) is a 6-item self-report measure designed to assess the six dimensions of sleep health: (1) regularity, (2) satisfaction, (3) alertness, (4) timing, (5) efficiency, and (6) duration. Respondents rate how often each item occurs (e.g., "Are you satisfied with your sleep?" "Do you stay awake all day without dozing?"), with responses

ranging from 0 (*rarely/never*) to 2 (*usually/always*). A total score (0-12) is calculated by taking the summation of each item score, with higher scores representing better sleep health. Preliminary psychometric evaluation of the RU SATED has supported it as a valid and reliable measure of sleep health among adults (Ravyts et al., 2019). The Cronbach's alpha for the RU SATED in the current sample was .64. Deletion of any scale items decreased the Cronbach's alpha for this measure, thus all items were retained.

Insomnia. The Insomnia Severity Index (ISI; Bastien et al., 2001) is a 7-item self-report measure designed to assess perceived insomnia severity over the past two weeks. Respondents rate the severity, nature, and impact of insomnia symptoms (e.g., "Difficulty falling asleep," "How satisfied/dissatisfied are you with your current sleep pattern," "To what extent do you consider your sleep problem to interfere with your daily functioning currently"), with responses ranging from 0 (e.g., *none, very satisfied, not at all interfering*) to 4 (e.g., *very severe, very dissatisfied, very much interfering*). A total score (0-28) is calculated by taking the summation of each item score, with higher scores representing more severe insomnia symptoms. Total scores categories include: non-clinically significant insomnia (0-7), sub-threshold insomnia (8-14), moderate insomnia (15-21), and severe insomnia (22-28). A cut-off score of 14 is recommended to maximize sensitivity and specificity of the measure's detection of an insomnia disorder (Morin et al., 2011a). The patient version of the ISI was used for this study. The ISI has been supported as a valid and reliable measure of insomnia severity among a general population of adults, in primary care, and when delivered as a web-based measure (Bastien et al., 2001; Gagnon et al., 2013; Morin et al., 2011b; Thorndike et al., 2011). The Cronbach's alpha for the ISI in the current sample was .89.

Mental Health

Anxiety. The Generalized Anxiety Disorder-2 (GAD-2; Kroenke et al., 2007) is an ultra-brief, 2-item self-report measure designed to assess anxiety symptoms over the past two weeks. Respondents rate the frequency with which they have experienced two core symptoms of anxiety (e.g., "Feeling nervous, anxious, or on edge" and "Not being able to stop or control worrying"), with responses ranging from 0 (*not at all*) to 3 (*nearly every day*). A total score (0-6) is calculated by taking the summation of the two items, with higher scores representing more severe anxiety symptoms. A cut-off score of 3 is recommended to maximize sensitivity and specificity of the measure's indication of an anxiety disorder (Plummer et al., 2016; Staples et al., 2019). The GAD-2 has been supported as a valid and reliable measure of anxiety symptoms among adults and in primary care settings (Kroenke et al., 2007; Plummer et al., 2016; Staples et al., 2019). The Cronbach's alpha for the GAD-2 in the current sample was .87.

Depression. The Patient Health Questionnaire-2 (PHQ-2; Kroenke et al., 2003) is an ultra-brief, 2-item self-report measure designed to assess depressive symptoms over the past two weeks. Respondents rate the frequency with which they have experienced two core symptoms of depression (e.g., "Little interest or pleasure in doing things" and "Feeling down, depressed, or hopeless"), with responses ranging from 0 (*not at all*) to 3 (*nearly every day*). A total score (0-6) is calculated by taking the summation of the two items, with higher scores representing more severe depressive symptoms. A cut-off score of 3 is recommended to maximize sensitivity and specificity of the measure's indication of a depressive disorder (Staples et al., 2019). The PHQ-2 has been supported as a valid and reliable measure of depressive symptoms among adults and in primary care settings (Kroenke et al., 2003; Staples et al., 2019). The Cronbach's alpha for the PHQ-2 in the current sample was .86.

Negative Affect. The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) is a 20-item self-report measure designed to assess positive and negative affect over the past two weeks. The ISLAND study used a 10-item short form of the PANAS (Kercher, 1992), where each subscale contains five items per subscale, rather than 10 items per subscale assessing positive and negative affect in the PANAS. For the proposed study, only the 5-item negative affect subscale was used. Respondents rated the extent they have felt a variety of negative feelings (e.g., distressed, upset, scared, afraid, nervous) in the past week, with responses ranging from 1 (*very slightly or not at all*) to 5 (*extremely*). A total score (5-25) for the negative affect subscale is calculated by taking the summation of all items, with higher scores indicating higher levels of negative affect over the past week. The negative affect subscale of the PANAS has been supported as a valid and reliable measure of negative affect among a general population of adults, as well as clinical and non-clinical samples (Crawford & Henry, 2004; Watson et al., 1988). The Cronbach's alpha for the negative affect subscale of the PANAS in the current sample was .89.

Sleep Self-Efficacy

The Sleep Self-Efficacy Scale (SSE; Lacks, 1987) is a 9-item self-report measure designed to assess self-beliefs of capacity to engage in sleep-related behaviors. Respondents rate the degree to which they are confident in their ability to carry out each sleep-related behavior (e.g., "Lie in bed, feeling physically relaxed," "Lie in bed, feeling mentally relaxed," "Wake up after a poor night's sleep without feeling upset about it"), with responses ranging from 1 (*not confident at all*) to 5 (very confident). A total score (9-45) is calculated by taking the summation of all items, with higher scores indicating greater sleep self-efficacy. The SES has been

supported as a reliable and valid measure of sleep self-efficacy (Lacks, 1987). The Cronbach's alpha for the SSE in the current sample was .88.

Loneliness

The de Jong-Gierveld Loneliness Scale (Gierveld & Tilburg, 2006) is a 6-item self-report measure designed to assess overall, emotional, and social loneliness. Respondents rate the degree to which each statement of emotional or social loneliness (e.g., "There are many people I can trust completely," "I miss having people around," "I often feel rejected") applies to them, with responses ranging from 1 (*YES!*) to 5 (*NO!*). This measure contains two subscales: emotional and social loneliness. Items 1-3 are negatively worded and represent emotional loneliness. Items 4-6 are positively worded and represent social loneliness. A total score (6-30) is calculated by reverse scoring items 4-6, and then taking the summation of all items, with higher scores indicating greater severity of overall loneliness. The 6-item de Jong-Gierveld Loneliness Scale has been supported as a valid and reliable measure of overall, emotional, and social loneliness among a general adult population (Gierveld & Tilburg, 2006). The Cronbach's alpha for the de Jong-Gierveld Loneliness Scale in the current sample was .86.

Physical Activity

For the ISLAND study, three items were developed to assess frequency of physical activity and sedentary time. (1) Respondents rated the average frequency with which they engage in moderate to strenuous exercise in days per week. (2) Respondents also rated the average amount of time (*hours, minutes*) they engage in moderate to strenuous exercise per day. (3) Respondents reported the average percentage (*0%-100%*) of their waking day they spend sitting. For the proposed study, items (1) and (2) assessing average exercise were used to estimate

average total amount of time per week participants engaged in moderate to strenuous exercise. This calculated quantity was used for data analyses.

Data Analytic Plan

Structural Equation Model

SPSS v.28 (IBM Corp, 2021) and AMOS v.28 (Arbuckle, 2021) were used to examine a structural equation model (SEM) to evaluate the direct and indirect relationships among sleep quality, sleep self-efficacy, loneliness, physical activity, and mental health symptoms. Sleep quality (represented by the ISI and RU SATED), physical activity (represented by daily and weekly exercise, and time spent sitting), and mental health (represented by the PHQ-2, GAD-2, and the negative affect subscale of the PANAS) were each conceptualized as latent variables. Sleep self-efficacy (SSE) and loneliness (6-item de Jong-Gierveld Loneliness Scale) were each assessed as manifest variables. For this analysis, it was hypothesized that lower sleep quality would be directly and negatively associated with sleep self-efficacy and physical activity; and, directly and positively associated with greater loneliness. It was also predicted that sleep self-efficacy and physical activity would each be directly and negatively associated with mental health symptom severity; and, that greater loneliness would be directly and positively associated with mental health symptom severity. Finally, it was predicted that each sleep self-efficacy, loneliness, and physical activity will mediate the relation between sleep quality and mental health symptom severity. The indirect effect of sleep quality on mental health was assessed using 2,000 bootstrapped samples and a 95% bias-corrected confidence interval.

Given the assumptions associated with SEM, the following statistical assumptions were assessed prior to analyses. The construction of the survey required that participants respond to every item, thus there were no missing data across variables. Data were assessed for the presence

of univariate outliers (z-scores of ±3 SDs) and multivariate outliers (Mardia's coefficient > 5). Univariate normality and multivariate normality were assessed via respective skewness and kurtosis statistics (< |2|). Multicollinearity was assessed based on the correlations of the latent construct variables and manifest variables that were not indicators of a latent variable (< .8). The present sample's total participants exceeded the recommended 200 participant sample size for a Structural Equation Model (SEM) (Kline, 2015).

Measurement Model. As a part of a two-step structural modeling strategy, first, a separate estimation of the measurement model was run, prior to the simultaneous estimation of the measurement and structural models. This measurement model provided an assessment of the convergent and discriminant validity of the latent factors (e.g., sleep quality, physical activity, mental health). Further, the measurement model in conjunction with the structural model enabled a comprehensive assessment of the full latent model. Goodness of fit of the measurement model was examined using supported guidelines: non-significant chi-square test, a root mean squared error of approximation (RMSEA) of ≤ .08 (Tabachnick et al., 2007), as well as the goodness of fit index (GFI), adjusted goodness of fit index (AGFI), normed fit index (NFI), incremental fit index (IFI), Tucker-Lewis index (TLI), and a comparative fit index (CFI) with recommended cutoffs of .90 for adequate fit and.95 for good fit (Byrne, 1994; Hu & Bentler, 1999). Further, the loadings of manifest variables on to their respective latent constructs will be evaluated based on beta-weights and *p*-values.

Structural Model. Following the measurement model, an estimation of the full structural model, including all latent and manifest variables, was run. This structural model provided an assessment of the relationships among the variables of interest. To address Aim 1 of the proposed study, this included evaluating the paths between sleep quality and mental health, with

sleep self-efficacy, loneliness, and physical activity serving as potential mediators. The structural goodness of fit for the SEM was examined using supported guidelines: non-significant chi-square test, a root mean squared error of approximation (RMSEA) of ≤ .08 (Tabachnick et al., 2007) as well as the goodness of fit index (GFI), adjusted goodness of fit index (AGFI), normed fit index (NFI), incremental fit index (IFI), Tucker-Lewis index (TLI), and comparative fit index (CFI) with a recommended cutoffs of .90 for adequate fit and.95 for good fit (Byrne, 1994; Hu & Bentler, 1999). Direct and indirect relationships among sleep quality, sleep self-efficacy, loneliness, physical activity, and mental health symptoms were evaluated using beta-weights and *p*-values.

Invariance Analysis

For Aim 2 of the proposed study, to examine whether the SEM differed for participants based on gender and age, invariance tests were run as a function of gender (i.e., male, female) as well as age group (i.e., 18-34, 35-54, 55+ years). Invariance analyses provided a comparison of overall model fit as well as the direct associations among variables between participants who identified as male versus female, and pairwise comparisons between young-, middle-, and older adult participants. Invariance analysis required that gender and age be dichotomized for comparison.

Results

Data Preparation

All variables passed univariate normality checks (skewness and kurtosis statistics < |2|), except for average hours of moderate-strenuous exercise per week. Adjusting outliers for average hours of moderate-strenuous exercise per week (z-score > |3.29|) did not reduce skewness and kurtosis below the threshold. Thus, a square root transformation was applied and reduced skewness (.56) and kurtosis (-.003) below the threshold (Tabachnick et al., 2007). Univariate

outliers (z-scores > 3.29) across variables that did not exceed 2% of the total sample (N = 2,300) were retained (Cohen, 2003). Linearity of the data was supported via bivariate scatterplot review. There was no missing data.

Descriptive Statistics

Overall, participant (N = 2,300) age ranged from 19 to 99 years (M = 44.1, SD = 16.78) and primarily identified as female (49.0%) and white (82.0%). The majority of the sample completed some college or more (89.3%), were married (51.7%), were employed (61.2%), and did not live alone (79.0%). A complete description of demographic characteristics of the sample are detailed in Table 1. The majority of participants (67.7%) endorsed being diagnosed or currently treated for at least one medical or mental health concern, with high blood pressure (25.5%), anxiety disorder (25.2%), depressive disorder (22.5%), and any sleep disorder (17.1%) most frequently endorsed. However, the current sample primarily endorsed subthreshold insomnia (M = 8.4, SD = 6.5), anxiety (M = 1.7, SD = 1.9), and depressive symptoms (M = 1.6, SD = 1.8), with most participants endorsing symptoms below the respective clinical cut-offs for each insomnia (20.6%), anxiety (27.3%), and depressive (23.9%) symptoms. Complete descriptive statistics of participant demographic characteristics are detailed in Table 1, health history in Table 2, sleep disorder history in Table 3, and sleep quality, mental health symptoms, sleep self-efficacy, loneliness, and physical activity in Table 4.

Table 1. Demographic Characteristics (N = 2,300)

Demographic Characteristic	Frequency		
	M (SD)	*n*	%
Age	44.1 (16.78)		
Gender			
Female		1128	49.0
Male		1005	43.7
Other		167	7.3
Racial/Ethnic Identity+			
White		1886	82.0
Black		175	7.6
Asian		141	6.1
Native American		34	1.5
Latinx		139	6.0
Pacific Islander		12	.5
Other Race		36	1.6
Education			
Less than High School		13	0.6
High School Graduate		157	6.8
GED or High School Equivalent		70	3.0
Some College		578	25.1
2-year Associate Degree		283	12.3
4-year Bachelors Degree		819	35.6
Masters		265	11.5
Doctorate		115	5.0
Marital Status			
Married or Living as Married		1189	51.7
Single or never married		768	33.4
Divorced		220	9.6
Widowed		97	4.2
Separated		26	1.1
Employment Status+			
Employed		1407	61.2
Retired		349	15.2
Unemployed		193	8.4
Student		176	7.7
Home Maker		146	6.3
Unable to Work or Disabled		77	3.3
Living Status			
Does Not Live Alone		1816	79.0
Lives Alone		484	21.0

Note. +the summation of frequency percentage exceeds 100% due to the original survey prompt for this item being "check all that apply."

Table 2. Health Treatment History (N = 2,300)

Health Concern	Frequency	
	n	%
High Blood Pressure	587	25.5
Anxiety Disorder	580	25.2
Depressive Disorder	517	22.5
Chronic Pain	404	17.6
High Cholesterol	341	14.8
Arthritis	274	11.9
Gastroesophageal Reflux Disease	239	10.4
Breathing Problems	235	10.2
Thyroid Disorders	166	7.2
Diabetes	157	6.8
Frequent Urination or Incontinence	136	5.9
Cancer	89	3.9
Heart Disease	73	3.2
Problem Drinking or Alcoholism	71	3.1
Substance Use (other than alcohol)	37	1.6
Stroke or TIA	26	1.1
Traumatic Brain Injury	14	.6
Other Mental Health Condition	161	7.0
None	765	33.3

Note. Participants reported whether they have been diagnosed and/or are being treated for any of the above medical and psychological conditions.

Table 3. Sleep Disorder History (N = 2,300)

Sleep Disorder	Frequency	
	n	%
Any Sleep Disorder	394	17.1
Sleep Apnea	207	9.0
Treated Sleep Apnea	133	5.8
Insomnia	199	8.7
Restless Leg Syndrome	65	2.8
Circadian Rhythm Disorder	12	.5
Narcolepsy	10	.4
REM Behavior Disorder	4	.2
Other Sleep Disorder	14	.6

Note. Participants reported whether they have ever been diagnosed for any of the above sleep disorders. The summation of frequency percentage exceeds 100% due to the original survey prompt for this item being "check all that apply."

Table 4. Descriptive Statistics of Sleep Quality, Mental Health Symptoms, Sleep Self-Efficacy, Loneliness, and Physical Activity (N = 2,300)

Variable	*M (SD)*	*n* (%)
Sleep Quality		
Sleep Health (RU SATED)[b]	7.7 (2.7)	
Insomnia (ISI)[a]	8.4 (6.5)	
Nonclinical Insomnia		1,827 (79.4)
Clinical Insomnia		473 (20.6)
Mental Health Symptoms		
Anxiety (GAD-2)[c]	1.7 (1.9)	
Anxiety Disorder Unlikely		1,671 (72.7)
Anxiety Disorder Likely		629 (27.3)
Depression (PHQ-2)[d]	1.6 (1.8)	
Depressive Disorder Unlikely		1,751 (76.1)
Depressive Disorder Likely		549 (23.9)
Negative Affect (PANAS)[e]	9.9 (4.7)	
Positive Affect (PANAS)[f]	14.3 (4.4)	
Sleep Self-Efficacy (SSE)[g]	29.5 (8.2)	
Loneliness (de Jong-Gierveld Loneliness Scale)[h]	8.9 (5.4)	
Physical Activity		
Avg Hrs of Exercise per Week	3.5 (5.5)	
Percentage of Day in Sedentary Behavior	62.9 (20.6)	

Note. Average Hours of Moderate-Strenuous Exercise per Week (Avg Hrs of Exercise per Week). Latent variables are italicized. [a] Insomnia measured on a scale from 0-28, cut-off score ≥ 14. [b] Sleep Health measured on a scale from 6-18. [c] Anxiety measured on a scale from 0-6, cut-off score ≥ 3. [d] Depression measured on a scale from 0-6, cut-off score ≥ 3. [e] Negative Affect measured on a scale from 5-25. [f] Positive Affect measured on a scale from 5-25. [g] Sleep Self-efficacy measured on a scale from 9-45. [h] Loneliness measured on a scale from 6-30.

Measurement Model

From the measurement model, skewness and kurtosis coefficients for all variables met criteria for univariate normality. Mardia's coefficient of 10.74 (critical ratio of 18.30) suggested that the variables were multivariate kurtotic. Upon inspection, multivariate outliers (via the square distance of Mahalanobis D^2) represented 0.83% of total cases. Although these multivariate outliers were likely the source of non-normality, outliers were retained in analyses to provide a more conservative estimate of fit, as their removal would artificially improve the

overall tested model. Further, Mardia's coefficient is sensitive to sample size and is more likely be significant with large sample sizes, skewness and kurtosis coefficients were below their thresholds, and multivariate outliers made up less than 2% of the total cases (Cohen, 2003). Nevertheless, the models should be interpreted in light of their potential to generate smaller path coefficients or worse fit statistic than might be expected with more normal distributions.

For the measurement model, goodness of fit was assessed using several parameters. The χ^2 test was statistically significant, χ^2 (19, N = 2,300) = 248.41, $p < .001$, suggesting that the model failed to fit the data. However, the significance of the χ^2 may be caused by the present study's large sample. The GFI (.98), NFI (.97), RFI (.95), IFI (.98), TLI (.96) and CFI (.98) were all indicative of good fit (≥ .95). The AGFI (.94) indicated adequate fit (≥ .90) and RMSEA (.07) indicated adequate fit (≤ .08). Taken together, these indices suggest that the measurement model was a good fit for the data, and thus no modifications were conducted to improve the model. All manifest variables that were indicators for latent variables loaded highly (all standardized *beta-weights* > .52 and all *p-values* < .001). Finally, the correlations among factors ranged in magnitude from .20 to .82. All factors were correlated at a magnitude of < .80, except for sleep quality and sleep self-efficacy, indicating that there is sufficient discriminant validity among the latent constructs to proceed to the structural model. Regarding multicollinearity, although sleep quality and sleep self-efficacy were correlated at -.82, this is likely inflated due to the very high factor loadings of the manifest variables (insomnia and sleep health) on to sleep quality. The measurement model with factor loadings (standardized regression weights) and correlations is presented in Figure 2.

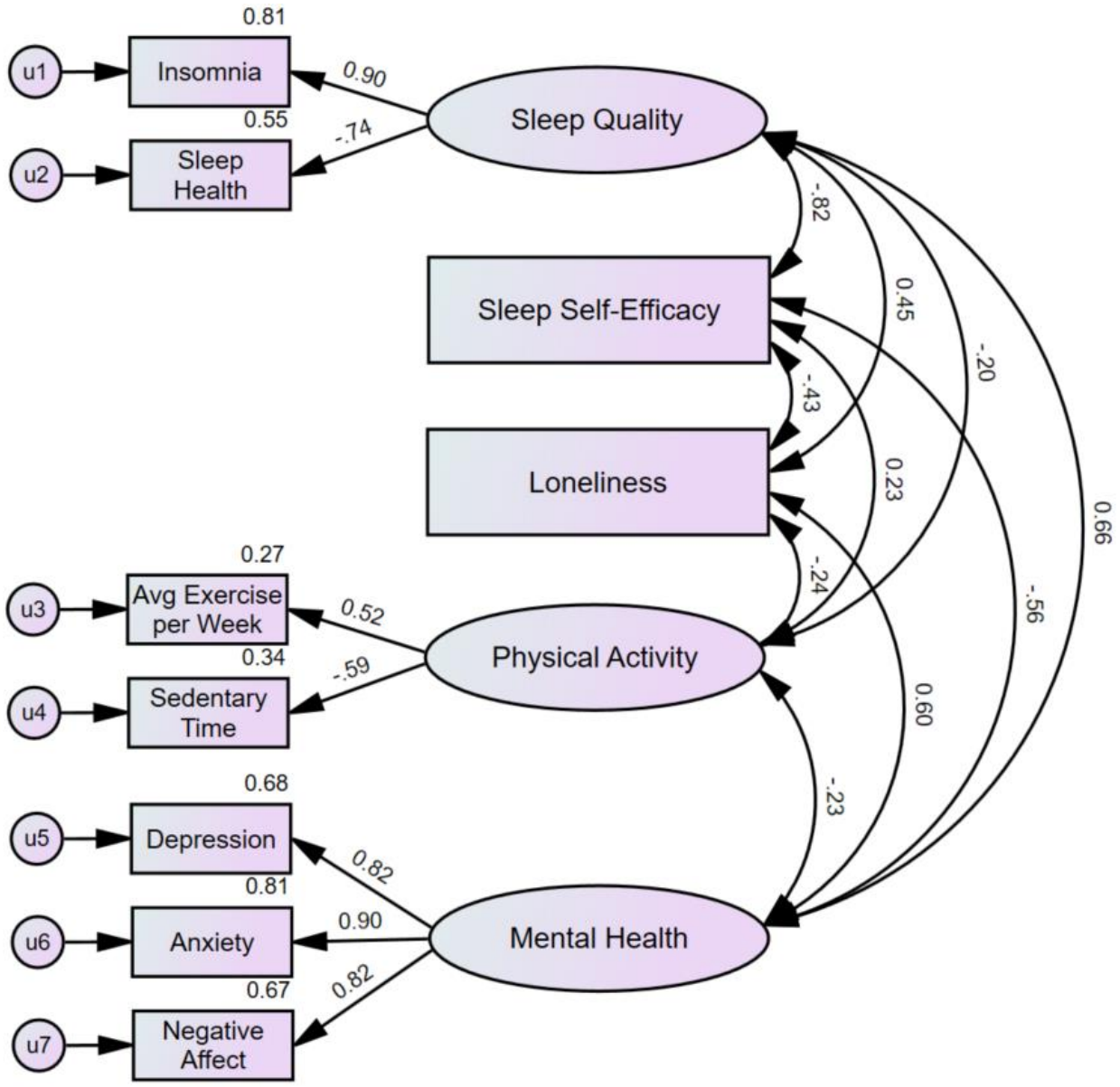

Figure 2. Measurement model of the proposed study. Strength of correlations among variables and factor loadings onto latent variables are shown.

Structural Model

The purpose of the structural model was to validate a hypothesized pattern of relationships among manifest and latent variables leading from sleep quality to mental health. For the structural model, the overall fit for the model was good. The χ^2 test was statistically significant, χ^2 (22, N = 2,300) = 300.058, p < .001, suggesting that the model failed to fit the

data. However, the significance of the $\chi 2$ may be caused by the present study's large sample. The GFI (.97), NFI (.97), RFI (.95), IFI (.97), TLI (.95) and CFI (.97) were all indicative of good fit (≥ .95). The AGFI (.94) indicated adequate fit (≥ .90) and RMSEA (.07) indicated adequate fit (≤ .08). Taken together, these indices suggest that the structural model was a good fit for the data, and thus no modifications were conducted to improve the model. Within this model, the direct paths from sleep quality to each proposed mediator, sleep self-efficacy, loneliness, and physical activity, were significant. In the context of the model, higher values in the latent variable sleep quality can be interpreted to represent poorer sleep quality, while lower values indicate better sleep quality. Similarly, higher values for the latent variable mental health can be interpreted as the presence of more severe mental health symptoms, while lower values indicate less severe mental health symptoms. Finally, higher values in the latent variable physical activity can be interpreted to represent more physical activity, while lower values represent less physical activity. Results indicated that participants who reported poorer sleep quality also endorsed poorer sleep self-efficacy (β = -.84, p < .001), greater loneliness (β = .48, p < .001), and less physical activity (β = -.24, p < .001). Sleep quality was also uniquely associated with mental health symptoms (β = .53, p < .001), indicating that participants who reported poorer sleep quality also endorsed more severe mental health symptoms. In contrast, the direct paths from each sleep self-efficacy (β = .04, p = .272) and physical activity (β = -.02, p = .441) were not significantly associated with mental health. However, the direct path from loneliness to mental health was significant (β = .36, p < .001), indicating that participants who reported greater loneliness also endorsed more severe mental health symptoms. Additionally, there was a statistically significant indirect effect of sleep quality on mental health (β = .14, p = .001), supporting the presence of a mediated relationship between sleep quality and mental health. The

structural model with standardized regression weights is presented in Figure 3. Although the data do not allow us to confirm which specific mediations are significant, we may infer that loneliness is the primary significant mediator, given that the direct associations from sleep self-efficacy and physical activity to mental health are low in magnitude and are not statistically significant. Overall, the structural model accounted for 55.2% of the variance in mental health symptoms, 70.7% in sleep self-efficacy, 23.0% in loneliness, and 5.8% in physical activity.

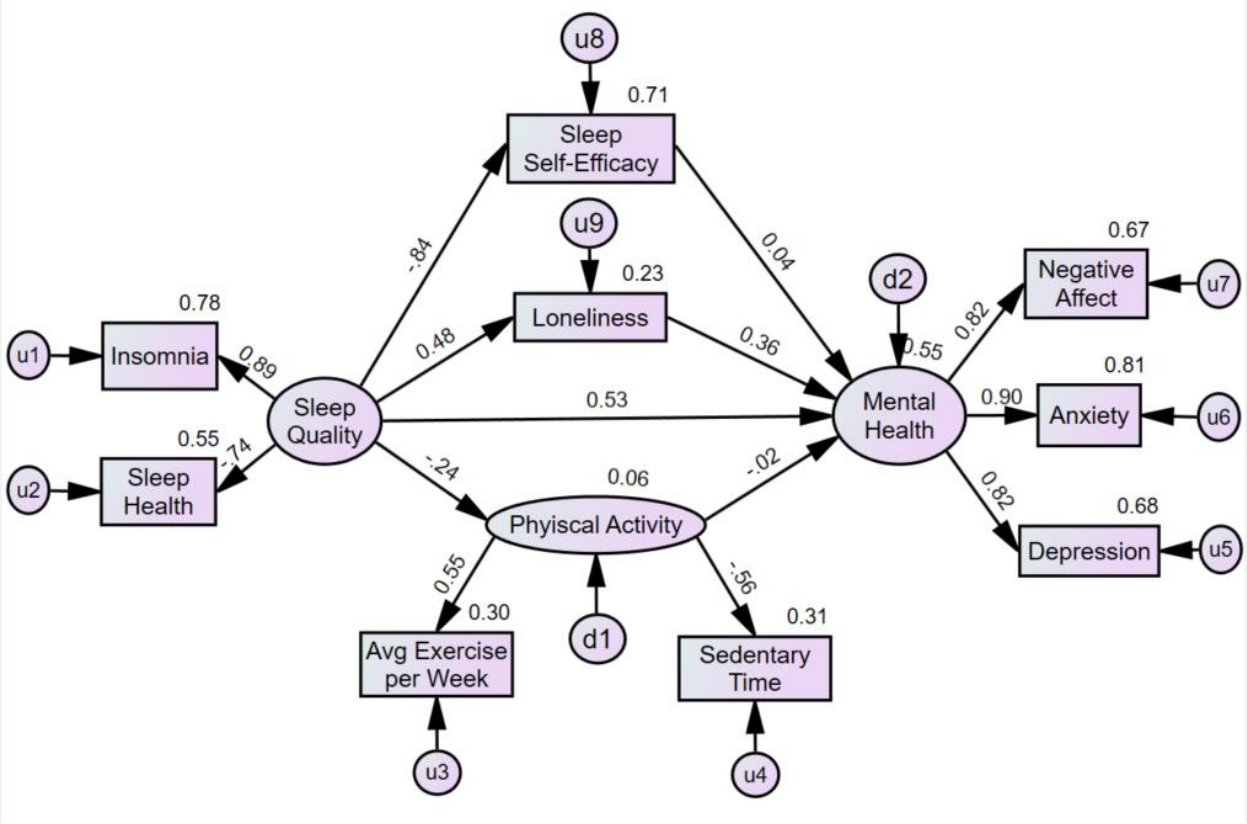

Figure 3. Final structural equation model. Strength and direction are shown of the relationships among variables.

Invariance Analysis

To determine whether the SEM differed between participants who identified as female and male or differed between age groups, an invariance design was employed as a function of gender as well as age group. The invariance analyses evaluated the difference between an unconstrained model, which assumes that the groups are yielding different parameter values

when the model is applied to the data, and a constrained model, which assumes that the groups are yielding equivalent parameter values. Invariance was assessed in two phases. First, omnibus comparisons allowed the examination of overall difference between groups. Four sets of comparisons were of interest: measurement weights, structural weights, structural residuals, and measurement residuals. Bonferronni-corrected post-hoc comparisons were performed determine which specific parameters differed between groups and to limit inflated risk of Type I error. To obtain omnibus comparison statistics for invariance analyses, participants were dichotomized.

For the evaluation of invariance by gender, in order to obtain omnibus comparison statistics, participants were dichotomized and those who identified as neither male nor female were excluded (n = 167, 7.3%). The first two sets of comparisons for measurement weights and structural weights were non-significant (all p-values > .088). However, comparison of the structural residuals ($\chi^2(14) = 39.26$, $p < .001$) and the measurement residuals ($\chi^2(23) = 58.74$, $p < .001$) did reach statistical significance, suggesting that men and women differed in the magnitude of the disturbance terms of the latent variables and uniqueness terms of the manifest variables in the model, respectively. Once Bonferroni-correction was applied, only the comparison for the error term for mental health was noninvariant across the men and women (z = 3.03). The error term for mental health was smaller among men (0.74) than among women (1.02), suggesting that mental health was a better index of symptom severity among men. Thus, it may be inferred that men and women can both be described by the SEM; however, this may be slightly less so for the specific aspect of the model accounting for error in the Mental Health latent factor. Despite this small caveat, the SEM generally showed overall strong invariance across men and women.

For the evaluation of invariance by age group, participants were categorized as young adults (ages 18-34, n = 817, 33.5%), middle-aged (35-54 years, n = 748, 32.5%), and older adults (55+ years, n = 735, 32.0%). In order to obtain omnibus comparison statistics, invariance tests were run for each pair of age groups: young adults and middle-aged adults, young adults and older adults, and middle-aged adults and older adults. For young adults relative to middle-aged adults, the first three sets of comparisons were nonsignificant (all p-values > .061). However, the measurement residual comparison did reach statistical significance ($\chi^2(23) = 64.303$, $p < .001$), suggesting that young adults and middle-aged adults differed in the magnitude of the uniqueness terms of the manifest variables in the model. Bonferroni-corrected post-hoc comparisons suggested that there were no statistically significant differences between young adults and middle-aged adults, such that the model was invariant in this regard across the two groups. Thus, it may be inferred that the SEM generally showed strong invariance across young adults and middle-aged adults, young adults and middle-aged adults can both be described by the SEM.

For young adults relative to older adults, all four comparisons reached statistical significance: measurement weights ($\chi^2(6) = 15.23$, $p = .019$), structural weights ($\chi^2(11) = 49.22$, $p < .001$), structural residuals ($\chi^2(14) = 57.02$, $p < .001$), and measurement residuals ($\chi^2(23) = 215.99$, $p < .001$). Regarding measurement weights (paths from measured variables to latent factors), and structural residuals (error terms of the latent factors), Bonferroni-corrected post-hoc comparisons suggested that there were no significant differences between young adults and older adults across these comparisons. Regarding structural weights (path coefficients) and measurement residuals (error terms of manifest variables), Bonferroni-corrected post-hoc comparisons suggested that only the path coefficient between loneliness and mental health (z = -2.67) and that the error terms for Anxiety (z = -6.31) and negative affect (z = -6.39) were

noninvariant across the young adults and older adults. Specifically, the path coefficient between loneliness and mental health was larger among young adults (β = 0.35) relative to older adults (β = 0.26), suggesting that the association was stronger among young adults. The error terms for anxiety and negative affect were smaller among older adults (0.38 and 4.91, respectively) relative to young adults (0.96 and 9.20, respectively), suggesting that anxiety and negative affect were better indices of symptom severity among older adults. Thus, young adults and older adults are described differently by the SEM, such that strength direct effect of loneliness on mental health is stronger among young adults relative to older adults.

For middle-aged adults relative to older adults, the comparison for measurement weights was non-significant (p =.300). However, all remaining comparisons did reach statistical significance: structural weights ($\chi^2(11) = 49.22$, $p < .001$), structural residuals ($\chi^2(14) = 57.02$, $p <.001$), and measurement residuals ($\chi^2(23) = 215.99$, $p <.001$). Regarding structural weights (path coefficients) and measurement residuals (error terms of the manifest variables), Bonferroni-corrected post-hoc comparisons suggested that there were no significant differences between middle-aged adults and older adults across these comparisons. Regarding structural residuals, Bonferroni-corrected post-hoc comparisons suggested that only the error term for mental health (z = -3.17) were noninvariant across middle-aged and older adults. Specifically, the error term for mental health was smaller among older adults (0.73) than among middle-aged adults (1.08), suggesting that mental health was a better of index of symptom severity among older adults. Thus, it may be inferred that middle-aged and older adults can both be described by the SEM; however, this may be slightly less so for the specific aspect of the model accounting for the error in the mental health latent factor. Despite these small caveats, the SEM generally showed overall good invariance across middle-aged and older adults.

Discussion

The purpose of the present study was to apply a cognitive behavioral model of mental health to characterize the associations between sleep quality, sleep self-efficacy, loneliness, physical activity, and mental health among adults across the lifespan. Thus, a theoretical SEM was developed to examine a hypothesized pattern among these variables, based on a cognitive behavioral framework of mental health. Specifically, it was hypothesized that the association between sleep quality and mental health would be mediated by variables representing each thoughts, feelings, and behaviors (i.e., sleep self-efficacy, loneliness, and physical activity, respectively). Further, it was hypothesized that the pattern of associations would differ based on gender as well as across age groups.

Aligned with hypotheses, the direct association between sleep quality and mental health was supported, such that worse sleep quality was positively associated with more severe mental health symptoms. Further, the direct associations between sleep quality and each proposed mediator were also supported, such that worse sleep quality was negatively associated with sleep self-efficacy, positively associated with greater loneliness, and negatively associated with more physical activity. Contrary to hypotheses, of the three parallel mediators, only the direct association between loneliness and mental health symptoms was significant, such that greater loneliness was positively associated with more severe mental health symptoms. However, an indirect effect of sleep quality on mental health symptom severity was supported, suggesting that only loneliness partially mediated the positive association between worse sleep quality and mental health symptom severity. The SEM explained 55.2% of the variance in mental health symptoms, 70.7% in sleep self-efficacy, 23.0% in loneliness, and 5.8% in physical activity. Finally, findings from the present study demonstrated that the model did not differ as a function of gender, contrary to hypothesis, but did differ on the path between loneliness and mental health

across young adults and older adults. Specifically, the model fit differed between young adults and older adults for the direct effect of loneliness on mental health, which was stronger among young adults relative to older adults. The present study's findings expand the current literature on the relationship between sleep and mental health by supporting sleep quality as a predictor of mental health and by investigating possible mediators explaining this connection.

Sleep Quality and Mental Health

The positive association between poor sleep quality and mental health symptom severity is consistent with and well supported in past research. Although past research has supported the presence of a complex and bidirectional relationship between sleep and mental health symptoms, with poor sleep exacerbating mental health symptoms and mental health symptoms negatively impacting sleep, recent meta-analyses support that disordered sleep temporally precedes and predicts the onset of psychiatric disorders and negative affect (Bouwmans et al., 2017; Hertenstein et al., 2019; M.-M. Zhang et al., 2022). While these findings are substantial, prior research has overwhelmingly been limited to investigating the specific relationship between insomnia and depression, neglecting other components of sleep as well as other relevant mental health symptoms. Thus, the present study's use of structural equation modeling and latent variables contribute to the current understanding of the relationship between sleep and mental health by examining these constructs holistically. Specifically, the findings support sleep quality, conceptualized to include both disordered and healthy sleep, as a predictor of mental health symptoms, including symptoms of depression, anxiety, and negative affect. When examining the relationship between sleep quality and mental health, past research has predominantly evaluated sleep quality via a single component of sleep health (e.g., sleep duration, sleep satisfaction) (Alvaro et al., 2013; Bouwmans et al., 2017; Zhai et al., 2015), relative to the six dimensions

defined by the RU-SATED. The present study's inclusion of a multi-dimensional measure of sleep health adds to the recently growing body of literature supporting that the composite of sleep health is associated with psychological distress (Appleton et al., 2022; Lee & Lawson, 2021). Sleep health is an important construct to be captured in future sleep research, expanding beyond a medical model and toward a wellness model.

Despite robust evidence that supports sleep quality as a predictor of mental health symptoms, research investigating the possible explanations of this relationship remains scarce. Moreover, research examining possible mediators between sleep quality and mental health has largely been limited to physiological explanations (e.g., changes in neuroplasticity, inflammation, hypothalamic-pituitary-adrenal axis activation). Thus, a novel aspect of the present study was its examination of cognitive behavioral explanations of the relationship between sleep quality and mental health. Findings expand on past research by contributing to a biopsychosocial model of health and wellbeing in the context of sleep and mental health.

Sleep Quality, Mental Health, and Sleep Self-Efficacy

The finding that sleep self-efficacy was not a significant mediator between sleep quality and mental health contrasts with patterns identified in prior research. Theoretical and empirical research exploring sleep, sleep self-efficacy, and mental health support patterns of associations that suggest sleep self-efficacy as a potential mediator between sleep quality and mental health. The 3P model of insomnia describes how predisposing, precipitating, and perpetuating factors contribute to the development and maintenance of insomnia (Spielman et al., 1987). Cognitive behavioral therapy for insomnia (CBT-I), the frontline treatment for insomnia, targets the perpetuating factors of insomnia – the thoughts, feelings, and behaviors, that sustain poor sleep (Mitchell et al., 2012; Spielman et al., 1987). Regarding sleep self-efficacy, poor sleep quality

contributes to the development of maladaptive thoughts about sleep, including poor sleep self-efficacy. While there is extremely limited research examining sleep self-efficacy, existing research has supported sleep self-efficacy to be associated with insomnia severity and as a predictor of depression and anxiety (Johnson & Hlaing, 2020; Rutledge et al., 2013; Sabet et al., 2021). The present study's inclusion of sleep self-efficacy contributes to growing the research examining this construct, particularly in relation to sleep quality and mental health.

Although sleep quality was a significant predictor of sleep self-efficacy, there are several considerations for why sleep self-efficacy was not supported as a mediator in the present study. First, given that sleep self-efficacy captures one specific form of realm-specific self-efficacy, other key components of self-efficacy that contribute to changes in mental health may be missing. Of note, general self-efficacy has been supported to predict changes in depression and anxiety (Tahmassian & Jalali Moghadam, 2011). General self-efficacy, rather than realm-specific self-efficacy, may mediate the relationship between sleep quality and mental health. Recent research modeling the role of self-efficacy in the relationship between disordered sleep and depressive symptoms among caregivers of stroke patients found evidence in support of self-efficacy as a mediator (Cong et al., 2021). Second, the associations among sleep self-efficacy, sleep quality, and mental health may have a different orientation than proposed. Preliminary research suggests that sleep self-efficacy predicts sleep quality in the elderly (Adachi et al., 2013), mediates the relationship between general self-efficacy and sleep quality (Schutte & Malouff, 2016), and may be an important predictor of patient outcomes in CBT-I (Lovato et al., 2013; Montserrat Sánchez-Ortuño & Edinger, 2010). Finally, the present study investigated sleep self-efficacy as a mediator among a general-population sample, whereas sleep self-efficacy may appear as a mediator between sleep quality and mental health specifically among those actively

engaged in CBT-I. The scarce literature that has examined sleep self-efficacy has done so in the context of patient populations engaged in CBT-I (Alshehri et al., 2021; Lovato et al., 2016; Siengsukon et al., 2021). CBT-I is indicated in the presence of disordered sleep, a component of sleep quality in the present study, and recent research has supported CBT-I as an effective method of prevention and treatment for depression (Cheng et al., 2022; Cunningham & Shapiro, 2018; Gee et al., 2019). Nevertheless, the findings of the present study add to the limited understanding of the role of sleep self-efficacy in relation to sleep quality and mental health. Sleep self-efficacy should continue to be evaluated in sleep research to determine its effects.

Sleep Quality, Mental Health, and Loneliness

A novel aspect of the present study was the finding support for loneliness as a mediator explaining the relationship between sleep quality and mental health. Although prior research exploring sleep quality, loneliness, and mental health symptoms supports a pattern of associations indicating loneliness as a potential mediator, loneliness has yet to be investigated in this role. Recent meta-analyses examining sleep quality and loneliness support a bidirectional relationship, though they also indicate that additional research examining sleep quality as a longitudinal predictor of loneliness is needed to draw conclusions (Griffin, Williams, Ravyts, et al., 2020; Hom et al., 2020). In support of sleep quality as a predictor of loneliness, poor sleep quality may lead to greater social withdrawal and increased loneliness. Specifically, a longitudinal study that closely followed behavior and sleep quality over a 3-week period found that greater sleepiness predicted reduced initiation and decreased duration of social interactions, with results strongest at times when socializing is most likely to occur – evenings and days off (Holding et al., 2020). Further, research suggests poor sleep quality activates social repulsion signals while also dampening prosocial signals in the brain, leading individuals to socially

withdraw and others to socially disengage with them (Ben Simon & Walker, 2018). Thus, in response to calls from past research to examine the relationships between sleep, loneliness, and depression, and aligned with interpretation from meta-analytic data (Griffin, Williams, Ravyts, et al., 2020; Hom et al., 2020), findings from the present study suggest that sleep quality may predict mental health symptoms by exacerbating loneliness.

Loneliness was the only significant mediator within the proposed theoretical SEM examining the relationship between sleep and mental health. This finding aligns with the substantial literature supporting loneliness as a predictor of mental health. Several recent meta-analyses support that loneliness temporally precedes and predicts the onset of mental health concerns (Mann et al., 2022; Park et al., 2020). While these findings are robust, these reviews highlight that, similar to sleep quality and mental health, research has predominantly investigated the relationship between loneliness and depression, specifically. Gaps identified in the literature examining loneliness as a predictor of mental health include examining this relationship across the lifespan and examining loneliness as a predictor of other mental health concerns (e.g., anxiety), rather than just depression (Mann et al., 2022; Park et al., 2020). Thus, the findings of the present study expand upon existing literature examining sleep quality, loneliness, and mental health by supporting loneliness as a mediator in a sample of adults across the lifespan, in relation to a holistic construct of sleep quality, and in relation to a latent construct of mental health which includes anxiety and negative affect in addition to depression. Results of the present study demonstrate that addressing loneliness may be indicated in sleep research and clinical intervention.

Sleep Quality, Mental Health, and Physical Activity

The finding that physical activity was not a significant mediator between sleep quality and mental health contrasts with patterns identified in prior research. Like sleep self-efficacy, physical activity has been identified as a potential mediator between sleep quality and mental health based on patterns of associations supported in past research. Although physical activity has primarily been examined as a predictor of sleep, with increased physical activity leading to improved sleep, growing sleep research has identified a bidirectional relationship that warrants further examination of sleep quality as a predictor of physical activity (Kline, 2015). The significant direct relationship between sleep quality and physical activity in the present study aligned with past research supporting sleep quality as a predictor of future physical activity in the short-term (Bernard et al., 2016; Liao et al., 2020; Pesonen et al., 2022) and long-term (Holfeld & Ruthig, 2014); and, was contrary to other research that did not support sleep quality as a predictor of physical activity (Atoui et al., 2021). In turn, physical activity has been widely supported as a predictor of concurrent and future mental health concerns. Specifically, those engaged in less physical activity and greater sedentary time are more likely to have more severe mental health symptoms (del Pozo Cruz et al., 2020; Schuch et al., 2017; Stanczykiewicz et al., 2019) and are more likely to develop a clinically significant psychiatric disorder (Huang et al., 2020; McDowell et al., 2019; Schuch et al., 2018; Svensson et al., 2021). Further, while increased physical activity protects against and reduces mental health symptoms (Brüchle et al., 2021; Svensson et al., 2021), treatment for anxiety does not lead to improvements in sleep or physical activity (Brown et al., 2022). Inconsistent with past research, physical activity in the present study, comprising moderate-strenuous exercise and sedentary time, was not found to be directly associated with mental health symptom severity.

Although there is support for examining physical activity as the link between sleep quality and mental health, prior studies have varied in their approach to characterizing these relationships. For example, one study identified sleep problems as the link between physical activity and depressive symptoms (Kaseva et al., 2019) and another identified sleep health as the link between physical activity and depressive symptoms (Barham et al., 2021). However, the present study is unique in its use of latent variables to examine more holistic version of these constructs. Another study examining sleep quality, physical activity, and mental health found support for anxiety and depression as mediators between physical activity and sleep quality (Su et al., 2021). Finally, another study examined mental health as a mediator between sleep quality and quality of life, with physical activity moderating the relationship between mental health and quality of life (Yuan et al., 2020). Although it is apparent that sleep quality, physical activity, and mental health symptoms are interrelated, the specific organization of their relationship has yet to be determined. Accordingly, the relationships among sleep quality, physical activity, and sleep quality may be oriented in a different way than examined or may be better explained by additional variables not included in the present study. Nevertheless, a review of the literature examining the epidemiology of sleep behavior, physical activity, and depression concluded that the substantial evidence supporting sleep and physical activity as predictors of depression suggests that the interaction between sleep and physical activity in the context of depression should be examined (Supartini & Kumagai, 2017). Specifically, it was recommended that research examine whether physical activity mediates the relationship between sleep and mental health; however, physical activity has rarely been examined in this role. Therefore, the finding of the present study that physical activity does not mediate sleep quality's association with mental

health contributes the current body of research by evaluating one of several possible models of these constructs, suggesting physical activity may serve a different role in this relationship.

Gender and Age Differences

The lack of evidence supporting a difference in the pattern of relationships between females and males as well as between age groups suggests that the theoretical model similarly describes genders and age groups, except for young adults and older adults. Specifically, results demonstrated that the magnitude of the direct relationship between loneliness and mental health in the model was stronger among young adults relative to older adults. Overall, these findings vary in their alignment with existing literature. Research examining changes in sleep quality as a function of gender and age suggests that sleep health does not vary by gender but does by age group (Dzierzewski et al., 2021; Ravyts et al., 2019), and that insomnia symptoms vary by age and gender (Kocevska et al., 2021). Regarding mental health symptoms, research suggests that depressive symptoms decrease with age and anxiety symptoms increase with age among women (Moulinet et al., 2022). Regarding physical activity, research suggests that physical activity demonstrates nonlinear changes by gender as well as age group (Varma et al., 2017). There was no evidence that variations in sleep quality, mental health, or physical health by age and gender affected model fit across gender and age groups, supporting the overall fit of the theoretical model. Of note, the direct effect between physical health and mental health was not significant. Regarding loneliness, research examining changes in loneliness as a function of gender and age suggest that loneliness may not vary as a function of gender as previously thought, but does vary by age, with higher loneliness among young adults and middle-aged adults, and lower loneliness among older adults (Hawkley et al., 2020). The lack of evidence that variations in the relationship between sleep quality and loneliness by age and gender affected model fit aligns

with prior research (Griffin, Williams, Mladen, et al., 2020), supporting the overall fit of the theoretical model. The finding of the present study that young adults relative to older adults have a stronger association between loneliness and mental health symptoms aligns with recent research supporting strong associations between loneliness and mental health symptoms among young adults (Steen et al., 2022). Thus, future research should examine whether the path between loneliness and mental health continues to be noninvariant between young and older adults across other populations.

Clinical Implications

The findings of the present study have several implications for clinical intervention development and implementation. First, the association between sleep quality and mental health elucidates the potential benefits of interventions targeting sleep. Supporting sleep quality by treating insomnia symptoms through interventions such as CBT-I may lead to improvements in mental health symptoms as well as protect against the development of future mental health concerns. Indeed, interventions targeting sleep lead to improvements in mental health across depression, anxiety, rumination, and stress (Scott et al., 2021). Thus, supporting sleep quality serves to support overall mental health and should also be routinely assessed and treated in the presence of mental health concerns as a standard of care. Moreover, the present study's examination of sleep quality comprising both disordered and healthy sleep suggests that prevention strategies and interventions targeting sleep should be developed to reduce disordered sleep as well as to bolster healthy sleep. Support for healthy sleep may be carried out across several domains, such as health care providers in the form of behavioral interventions (e.g., stress management, relaxation techniques, exercise), places of employment in the form of educational programming and organizational changes (e.g., lighting in the office, exercise opportunities,

screening for sleep treatment needs), and federal and local government in the form of policy change (e.g., later school start times) (Albakri et al., 2021; Murawski et al., 2018; Redeker et al., 2019).

Second, the finding of the present study that loneliness mediates the relationship between sleep quality and mental health suggests that loneliness is a key target for intervention. Assessing for and addressing loneliness in the presence of sleep quality or mental health concerns may support overall outcomes. Those with poor sleep quality may have more difficulty accomplishing goals or may be more likely to disengage from meaningful activities and social relationships. As such, lacking sense of purpose and meaning in life are tied to increased feelings of loneliness and greater risk for developing loneliness (Macià et al., 2021; Sutin et al., 2022). Thus, changes in thoughts and behaviors related to loneliness should be monitored in the context of poor sleep quality. Furthermore, psychological and behavioral interventions (e.g., cognitive behavioral therapy to address maladaptive social cognitions, social identity approaches) effectively reduce loneliness and may easily be integrated into treatment for sleep or mental health (Hickin et al., 2021; Masi et al., 2011). Given that the relationship between sleep quality and mental health may be explained by loneliness, targeting loneliness as a part of intervention for sleep may support overall mental health. The relationship between loneliness and mental health was stronger among young adults relative to older adults in the present study, suggesting that these clinical implications may be particularly important among young adults.

Finally, sleep self-efficacy and physical activity were not supported as mediators of the relationship between sleep quality and mental health, suggesting that other cognitive and behavioral mechanisms may be stronger targets for intervention or that these constructs may be related to one another in a different temporal orientation. Other possible cognitive and behavioral

mechanisms explaining the relationship between sleep quality and mental health include emotion regulation and coping styles, respectively (Niu & Snyder, 2022; Y. Zhang et al., 2018).

Strengths, Limitations, and Future Directions

The present study's findings must be interpreted in the context of the study's strengths and limitations. First, the present study's cross-sectional design prevents causal and temporal conclusion from being made. For example, the present study and prior research suggest that sleep quality predicts mental health symptoms (Hertenstein et al., 2019; M.-M. Zhang et al., 2022), but other extant literature has also supported a bidirectional relationship between sleep quality and mental health, such that mental health may predict sleep quality in the present study's sample. Multilevel longitudinal mediation analyses are superior in detecting mediation effects; however, when multilevel longitudinal mediation is not possible, the use of cross-sectional mediation analyses is supported (Cain et al., 2018). Future research may more precisely identify the temporal and causal relationships of the theoretical model examined in the present study via longitudinal designs examined via multilevel longitudinal mediation or experimental designs. Ecological momentary assessment may also assist in determining whether predictive effects occur rapidly. Second, though the present study's measurement of physical activity was a latent factor comprising of both exercise and sedentary time, this variable may be limited by the lack of differentiation in type of exercise and sedentary time. For example, passive sedentary behavior (e.g., watching television) was predictive of depression, whereas mentally active-sedentary behavior (e.g., reading, problem solving) reduced the risk of depression, but total sedentary behavior does not significantly predict depression (Hallgren et al., 2018, 2020). Intensity levels of leisure and non-leisure physical activity are also differentially associated with depression (Meng et al., 2021). Future research should compare the specific types of each exercise and

sedentary behavior in relation to sleep quality and mental health. Moreover, although all other constructs were measured by well validated-measures, data was collected exclusively via self-report and, thus, are subject to bias, sleep quality in particular. Future research should include subjective as well as objective (i.e., actigraphy) measures of sleep, though subjective measures of sleep but not objective measures of sleep have been predictive of depression (M.-M. Zhang et al., 2022). There was also relatively low internal consistency of the RU-SATED in the present sample, though the examination of both healthy and disordered sleep in the present study was a strength. Third, the present sample was predominantly White, educated, had access to internet to complete the online survey, and examined gender primarily as a binary variable, limiting the generalizability of the results. Of note, the present study's large sample comprising U.S. adults across the lifespan is a strength. Further, important sociodemographic determinants of health (e.g., socioeconomic status, health insurance status, sexuality) that are implicated in sleep quality and mental health were not assessed. Future research should consider how such factors may be evaluated in the model.

Conclusions

Despite the strong support for sleep quality as a predictor of mental health in the literature, there has been relatively little research examining possible explanations of this relationship. Overall, the findings of the present study extend past research by supporting sleep quality as a predictor of mental health symptoms, evaluating possible explanations for this relationship, and providing initial evidence of an indirect effect of sleep quality on mental health through loneliness among a sample of U.S. adults across the lifespan. Additionally, the relationship between loneliness and mental health symptoms may be stronger among young adults relative to older adults. Findings of the present study suggest that assessing for and

treating poor sleep quality and loneliness lead to improvements in mental health. Although sleep self-efficacy and physical activity were not supported as mediators between sleep quality and mental health, alternative proposals for their role within this relationship were provided. Sleep problems and mental health concerns continue to rise in the U.S. and are tied to vast negative health outcomes and financial cost. Therefore, further research is needed to improve the understanding of this relationship to support health and wellbeing among U.S. adults of all ages.

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Appendix A: RU SATED Scale (Sleep Health)

The following questions are related to sleep. Please respond by marking one box per row.

	Rarely/Never (1)	Sometimes (2)	Usually/Always (3)
Do you go to bed and get out of bed at the same time (within one hour) every day? (1)	○	○	○
Are you satisfied with your sleep? (2)	○	○	○
Do you stay awake all day without dozing? (3)	○	○	○
Are you asleep (or trying to sleep) between 2:00 a.m. and 4:00 a.m.? (4)	○	○	○
Do you spend less than 30 minutes awake at night? (This includes the time it takes to fall asleep plus awakenings during sleep.) (5)	○	○	○
Do you sleep between 7 and 9 hours per day? (6)	○	○	○

Buysse, D. J. (2014). Sleep Health: Can We Define It? Does It Matter? *Sleep*, *37*(1), 9–17. https://doi.org/10.5665/sleep.3298

Appendix B: Insomnia Severity Index (ISI)

For the following questions, your answers should indicate the most accurate reply for the majority of days and nights.

During the past **TWO WEEKS**...

How severe was your problem falling asleep during the past **TWO WEEKS**?

- ○ Mild (1)
- ○ Moderate (2)
- ○ Severe (3)
- ○ Very severe (4)

How severe was your problem staying asleep during the past **TWO WEEKS**?

- ○ Mild (1)
- ○ Moderate (2)
- ○ Severe (3)
- ○ Very severe (4)

How severe was your problem of waking up too early during the past **TWO WEEKS**?

- ○ Mild (1)
- ○ Moderate (2)
- ○ Severe (3)
- ○ Very severe (4)

During the past **TWO WEEKS**, how satisfied or dissatisfied have you been with your sleep patterns?

- ○ Very satisfied (1)
- ○ Satisfied (2)
- ○ Mildly satisfied (3)
- ○ Dissatisfied (4)
- ○ Very dissatisfied (5)

During the past **TWO WEEKS**…

	Not at all (1)	A little (2)	Somewhat (3)	Much (4)	Very much (5)	I don't have a sleep problem (6)
To what extent have you considered your sleep problem to interfere with your daily functioning (such as daytime fatigue, your mood, or your memory)? (1)	○	○	○	○	○	○
How noticeable to others do you think your sleeping problem is in terms of impairing the quality of your life? (2)	○	○	○	○	○	○
How worried or distressed are you about your current sleep problem? (3)	○	○	○	○	○	○

Bastien, C. H., Vallières, A., & Morin, C. M. (2001). Validation of the Insomnia Severity Index as an outcome measure for insomnia research. *Sleep Medicine*, *2*(4), 297–307. https://doi.org/10.1016/S1389-9457(00)00065-4

Appendix C: Generalized Anxiety Disorder-2 (GAD-2) and Patient Health Questionnaire-2 (PHQ-2)

Please answer the following questions about your mood.

Over the past 2 WEEKS, how often have you been bothered by any of the following problems?

	Not at all (1)	Several days (2)	More than half the days (3)	Nearly every day (4)
Little interest or pleasure in doing things (1)	○	○	○	○
Feeling down, depressed, or hopeless (2)	○	○	○	○
Feeling nervous, anxious, or on edge (11)	○	○	○	○
Not being able to stop or control worrying (7)	○	○	○	○

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2003). The Patient Health Questionnaire-2: Validity of a Two-Item Depression Screener. *Medical Care*, *41*(11), 1284–1292. JSTOR. http://www.jstor.org/stable/3768417

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Appendix D: Positive and Negative Affect Schedule (PANAS) Short Form

Please answer the following questions about your mood.

Please indicate the extent to which you have experienced the following emotions in the last 2 WEEKS by selecting a choice from those presented.

	Not at all (1)	A little (2)	Moderately much (3)	Quite a bit (4)	Very (5)
Distressed (1)	○	○	○	○	○
Excited (5)	○	○	○	○	○
Upset (6)	○	○	○	○	○
Scared (7)	○	○	○	○	○
Enthusiastic (8)	○	○	○	○	○
Alert (9)	○	○	○	○	○
Inspired (10)	○	○	○	○	○
Nervous (11)	○	○	○	○	○
Determined (12)	○	○	○	○	○
Afraid (13)	○	○	○	○	○

Kercher, K. (1992). Assessing subjective well-being in the old-old: The PANAS as a measure of orthogonal dimensions of positive and negative affect. *Research on Aging*, *14*(2), 131–168.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063.

Appendix E: The Sleep Self-Efficacy Scale (SSE)

Please answer the following questions about your sleep.

For the following nine questions, rate your ability to carry out each behavior. If you feel able to accomplish a behavior some of the time but not always, you should indicate a lower level of confidence.

	Not confident at all				Very Confident
	1	2	3	4	5
Lie in bed, feeling physically relaxed (1)	○	○	○	○	○
Lie in bed, feeling mentally relaxed (2)	○	○	○	○	○
Lie in bed with your thoughts "turned off" (3)	○	○	○	○	○
Fall asleep in under 30 minutes (4)	○	○	○	○	○
Wake up at night fewer than 3 times (5)	○	○	○	○	○
Go back to sleep within 15 minutes of waking in the night (6)	○	○	○	○	○
Feel refreshed upon waking in the morning (7)	○	○	○	○	○
Wake after a poor night's sleep without feeling upset about it (8)	○	○	○	○	○
Not allow a poor night's sleep to interfere with daily activities (9)	○	○	○	○	○

Lacks, P. (1987). *Behavioral treatment for persistent insomnia.* Pergamon Press.

Appendix F: The de Jong-Gierveld Loneliness Scale

Please answer the following questions about how you feel.

Please indicate for each of the following statements, the extent to which they apply to your situation, **the way you feel now.**

	YES! (1)	yes (2)	more or less (3)	no (4)	NO! (5)
I experience a general sense of emptiness. (1)	○	○	○	○	○
I miss having people around me. (5)	○	○	○	○	○
I often feel rejected. (6)	○	○	○	○	○
There are plenty of people I can rely on when I have problem. (7)	○	○	○	○	○
There are many people I can trust completely. (8)	○	○	○	○	○
There are enough people I feel close to. (9)	○	○	○	○	○

Gierveld, J. D. J., & Tilburg, T. V. (2006). A 6-item scale for overall, emotional, and social loneliness: Confirmatory tests on survey data. *Research on Aging*, *28*(5), 582–598.

Appendix G: Physical Activity

We want to ask you about your physical activity.

Moderate exercise (like fast walking, swimming, bicycle at medium pace) takes moderate physical effort, makes you breathe somewhat harder than normal, and gives you a moderate increase in heart rate, but is not exhausting.

Strenuous exercise (like running, aerobic exercise class, and spin class) takes hard physical effort, makes you breathe much harder than normal, and makes your heart beat a lot faster than normal.

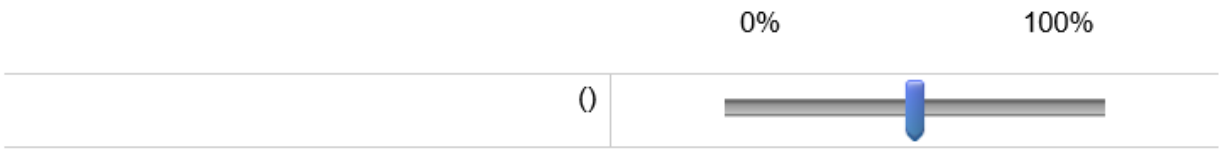
On average, how many **days per week** do you engage in **moderate to strenuous** exercise?

On average, how much time **per day** do you engage in **moderate to strenuous** exercise?
Hours (1)
Minutes (2)

On average, what **percentage** of your waking day do you spend sitting?

(Please include time spent at work, at home, while doing course work, and during leisure time. This may include time sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.)

*Note: If the slider is already in the correct position for your response, please click the slider without moving it so the survey will record your response.



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